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Projecting travelers into a world of self-driving vehicles: estimating travel behavior implications via a naturalistic experiment

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Abstract

Automated driving technologies are currently penetrating the market, and the coming fully autonomous cars will have far-reaching, yet largely unknown, implications. A critical unknown is the impact on traveler behavior, which in turn impacts sustainability, the economy, and wellbeing. Most behavioral studies, to date, either focus on safety and human factors (driving simulators; test beds), assume travel behavior implications (microsimulators; network analysis), or ask about hypothetical scenarios that are unfamiliar to the subjects (stated preference studies). Here we present a different approach, which is to use a naturalistic experiment to project people into a world of self-driving cars. We mimic potential life with a privately-owned self-driving vehicle by providing 60 h of free chauffeur service for each participating household for use within a 7-day period. We seek to understand the changes in travel behavior as the subjects adjust their travel and activities during the chauffeur week when, as in a self-driving vehicle, they are explicitly relieved of the driving task. In this first pilot application, our sample consisted of 13 subjects from the San Francisco Bay area, drawn from three cohorts: millennials, families, and retirees. We tracked each subject's travel for 3 weeks (the chauffeur week, 1 week before and 1 week after) and conducted surveys and interviews. During the chauffeur week, we observed sizable increases in vehicle-miles traveled and number of trips, with a more pronounced increase in trips made in the evening and for longer distances and a substantial proportion of "zero-occupancy" vehicle-miles traveled.

Keywords Travel behavior · Self-driving vehicles · Naturalistic experiment · Chauffeur · VMT

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Introduction

"Every new transportation technology affects the geography of communities and the structure of people's lives. Self-driving cars is such a technology. Just like freeways shaped past cities and lifestyles, self-driving vehicles will remake the metropolis once again" (Walters and Calthorpe 2017). While the date of market entry of fully self-driving cars that do not require human backup is uncertain, the reality is not. More and more automated features are being introduced into new vehicles currently on the market, self-driving cars are operating on our roads with a human backup, and fully self-driving vehicles (sans human backup) are operating under controlled environments. Tesla reports 780 million miles have been driven using its Autopilot; Uber and Volvo have shared, self-driving cars deployed in Pittsburg; and Waymo is now operating self-driving minivans in a suburb of Phoenix without a human backup. Governments in the US and around the world are racing to develop the necessary legislation that embraces the technology while ensuring the safety of its citizens, and planning agencies are struggling to update policies and plans to best realize a future with self-driving cars.

There is much speculation regarding the impact of self-driving cars on the transport system. On one hand, the improvements in safety and efficiency are thought by many to be the answer to our transportation problems, with most images of self-driving car futures implying safe and freely flowing roadways. However, others project a dystopian future where the efficiency improvements, while real, are not enough to counteract the trends of increasing population, increasing urbanization, increasing vehicle-miles traveled per capita, and induced demand. Many believe the key to a utopian future is a shared, self-driving fleet. Each of these futures is purely speculative. While it is not certain which future beckons, there is certainty that human behavior will be central to determining the outcome. And, yet, little is known about how travel will change with self-driving cars.

The literature distinguishes between different levels of vehicle automation. Here we are focused on understanding traveler behavior implications for full automation, where vehicles can operate without any human intervention and without a human in the vehicle. This stage has the potential for the most radical traveler behavior changes, and these implications are the least understood today. The introduction of self-driving cars is expected to catalyze changes in travel behavior, activity participation, and land use. It is hypothesized to affect the value of travel time (e.g., via increased comfort and multitasking) and therefore the amount of travel. It likely will affect the quantity and type of vehicle purchases as well as the related decisions of whether to own a vehicle or opt for models of shared ownership. In the long run, it can affect decisions such as where to live and work, thereby impacting land-use.

It is difficult to predict the future of mobility after the adoption of self-driving vehicles for the simple reason that they do not currently exist. However, it is possible to project people into a world that includes some of the more salient features of self-driving cars. The biggest difference in using a self-driving car, and arguably the feature that will cause the most change in travel behavior, is not having to be behind the wheel personally driving the car or even to be in the car at all as it travels from one place to another. This feature relieves people from the duty of paying attention to the road, allowing them to make better use of their in-vehicle time. Moreover, it permits sending empty cars (zero-occupancy vehicles or ghost cars) on errands like charging the car, picking up a pizza, or dropping off laundry. Finally, it opens up a major new option for individuals with disabilities, individuals without a driver's license, and elderly who can no longer drive or are not confident anymore in their driving ability and reaction time.

Here, we implement via the use of personal chauffeurs a naturalistic experiment that aims to create familiarity with this coming technology that, until a few years ago, lay in the realm of science fiction. Our objective in providing subjects with a personal chauffeur is that we are essentially providing the "software" of a self-driving car, relieving them from the duty of personally driving the car or physically being in the car when the car is making trips. This enables people to experience and act directly on how their travel and activities may change if they were to own a self-driving car,[1] and it allows us to study such potential shifts. We present in this paper results from a beta-test of 13 San Francisco Bay Area households.

Literature review

Three main approaches are currently being used to gain insight into the potential impacts of self-driving cars: driving simulators and controlled testbeds, stated preference studies, and simulation based/scenario analysis studies.

Driving simulators and controlled test beds are extremely useful for studying safety and human factors issues associated with a given trip. For example, Jamson et al. (2013) examined multitasking behaviors and fatigue via a driving simulator. However, they are not as useful for investigating impacts on travel and activity behaviors.

Stated preference studies ask subjects to imagine how they would feel toward, pay for, and use automated vehicles in a hypothetical scenario. For example, Cyganski et al. (2015) and Schoettle and Sivak (2014) examined multitasking intention; Bansal and Kockelman (2016), Milakis et al. (2015), and Zmud and Sener (2017) examined a host of issues regarding autonomous vehicles, including willingness to pay for automation, mode choice, auto ownership, potential to adopt shared autonomous vehicles, and intention to move; and using a discrete choice framework, Daziano et al. (2017) performed an in-depth analysis of willingness to pay for autonomous features, Lavieri et al. (2017) studied adoption and use of the technology, Kolarova et al. (2018) studied the change in value of in vehicle travel time, and Felix and Kay (2017) studied for which types of trips and purposes people will use automated vehicles. While a valuable technique, particularly to gain initial insight, it is problematic to employ in situations where the context is too far from situations in which the subjects have placed themselves or could consider placing themselves. This is precisely the situation with self-driving cars.

Research using agent-based micro simulators (e.g., large-scale urban travel demand models) and network analysis (e.g., optimizing over the number of vehicles needed to serve a given demand) are particularly relevant to our study, as this literature includes predictions of the magnitude of the vehicle-miles traveled (VMT) increase induced by self-driving cars. Because the behavioral impacts of autonomous vehicles are currently largely unknown, such studies have thus far assumed the travel behavior response either by assuming a fixed demand or making assumptions regarding parameters in a travel demand model. For example, Fagnant and Kockelman (2014) generated demand from a trip-based model

[1] A complement to our experiment would be to investigate the travel behavior impacts if people were to make use of a shared fleet of self-driving vehicles (rather than private ownership), and this is left for future research.

under current behavioral conditions, and then performed a network analysis to see how this demand could be served by a shared, self-driving fleet. Their simulation results indicate that the number of cars necessary to serve the demand is drastically reduced (to about 10%) but that the relocation of vehicles between trips leads to a 10% increase in VMT. Schoettle and Sivak (2015) simulated self-driving car scenarios using NHTS travel diary data, where they assumed that a single household vehicle could shuttle between trips made by multiple household members. They found that in the most extreme cases the ability of the car to autonomously return home would result in a 75% increase in VMT.

Rather than focusing on fixed/current demand, another line of research has modified existing travel demand models to reflect potential behavioral and system changes. Childress et al. (2015) modified the PSRC (Seattle) activity-based model to study the impact of privately owned self-driving cars under different scenarios. Their four scenarios were based on assumptions of reduced parking costs, increased operating costs, decreased value of time, and increased network capacity. Their results varied across scenarios with increases in VMT ranging from 4 to 20%. Fehr & Peers (Biersted et al. 2014) also studied the impact of personal self-driving cars on VMT. After making assumptions on market penetration of the technology, level of service of transit, vehicle cost, and highway capacity increase, the results indicate that with a 50% market penetration, private self-driving cars will result in a 5% to a 20% increase in VMT, and this number rises to 35% with full market saturation. Both PSRC and Fehr & Peers assume fairly marginal impacts on travel behavior in that the basic decision protocols and transport system are fairly consistent with the status quo. The International Transport Forum (2015), in their analysis in Lisbon, pushed the status quo farther in terms of the behavioral assumptions and the transport system configuration. They made assumptions on the demand for the technology, the quality of service of public transit, the trip generation process, parking, car sizes, and the market penetration of the technology. Their results vary by scenario, with their most extreme outcome arising from the case of 50% market penetration of single-passenger self-driving taxis, which leads to a VMT increase of 90%.

These examples illustrate the extent of the assumptions necessary to run these simulations and the wide discrepancy across the literature of the predicted increase in VMT: from a low of 4% to a high of 90%. Further, key assumptions regarding the travel and activity behavior modifications are largely unknown and untested. Notably, Childress et al. (2015) point out that “this behavior (decrease of VOT), of course, has not been revealed or even stated by drivers, and at this point is speculation based on other modes of transport.” Our objective with this experiment is to provide more directly revealed evidence regarding the potential travel behavior impacts of self-driving vehicles to inform the otherwise untested assumptions of future studies.

Experimental design

The key components and flow of the experiment are presented in Fig. 1. First, both subjects and chauffeurs were recruited and onboarded. Next came the heart of the experiment: the 3 weeks of tracked travel, with the chauffeur intervention occurring in the middle week. The literature (Gertler et al. 2011) suggests that such a 3-week format, particularly when occurring over a relatively short time period, allows us to treat the two status quo weeks as a control for the treatment week. An online survey was administered before and after the three travel weeks. Each of these components is described in more detail below.

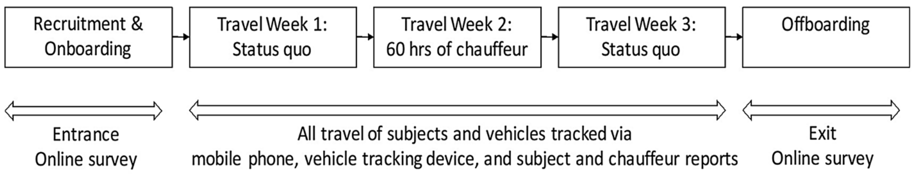

Fig. 1 Flow of experiment and primary data collected

Subject recruitment and on boarding

Our objective was to recruit a sample that would be illustrative (albeit not necessarily representative) of people who would potentially own self-driving cars. Given resource constraints, we chose to target three different cohorts that represent distinct lifecycle stages: Millennials, Families, and Retirees. We hypothesized that the impact of self-driving vehicles may vary across the cohorts as they have markedly different lifestyles. For example, Millennials may rely more on ride-hailing services than other generations. For Retirees, time of day and trip length may be relatively more important factors. For Families, kids and their activities are often a priority.

We recruited subjects via a number of channels. We posted advertisements to a UC Berkeley Facebook group, a Nextdoor neighborhood social network, and a retirement community newsletter. We also recruited via word of mouth from our research group and our subjects. Subjects who responded to our recruitment were screened to ensure that they met all of the following criteria:

- Be 18 years or older,
- Live within the 9-county San Francisco Bay Area,
- Possess a current driver's license and currently drive,
- Own a private car and don't currently use a chauffeur, and
- Possess a mobile phone with location services.

For subjects who met the criteria, we started the onboarding process. We continued recruiting until we reached our target number of 4 subjects within each cohort (and we ended up with 5 retirees). A key to the success of the experiment is that the subject understands what a self-driving car is and its potential benefits, and how a personal chauffeur simulates these. For this purpose, subjects took part in a 30–60 min one-on-one entrance interview via telephone. The household member who participated in this interview is deemed the "primary subject." The primary subjects were informed about the experiment. They were given information on self-driving cars, and they were informed of the potential errands that the technology will be able to run and that the chauffeur will be able to run these errands for them as well. The aim of the interviews was also to have subjects in a futuristic mindset before they are provided with the service, potentially minimizing the time it takes subjects to get used to their new "self-driving car." We also requested that other adult household members formally participate in the experiment so that we could collect survey data from them and track their movements, although this wasn't required.

The subjects were asked to choose a typical 3-week period void of special events such as holidays or travel. They were instructed to choose only one vehicle in the household to be used by the chauffeur and not have the chauffeur jump between multiple vehicles. This vehicle is deemed the "primary vehicle." Further, they were allowed to loan the service to friends or family, but if doing so, they had to loan the primary vehicle along with the chauffeur. While our experiment does not consider the additional purchase price of a self-driving car, the subjects are covering the full operating costs of their vehicles which is the relevant (marginal) cost considered in personal travel decisions once the vehicle is purchased.

Chauffeur recruitment and on boarding

Different chauffeur solutions were investigated, and the decision was to use a designated driver service that provides chauffeurs for hire using customer-owned vehicles (*Dryver*). A unique relationship with the company was established to ensure it could accommodate our experiment. The advantages of our chauffeur service include the use of the subject's car (reducing the costs of the experiment and making costs and the experience more realistic for the subject) and the liability being covered by the company rather than the research team, which eased the approval process from UC Berkeley. Similar to the subjects, chauffeurs took part in a one-on-one entrance interview where they were instructed about the experiment they would be participating in, as well as the technology and all its features that they would be simulating. The chauffeur was with the owner's vehicle at all times during the 60 allocated hours and served at the beck and call of the owner. The cost of the chauffeur service totaled roughly $1250 per household.

Data collection: tracking

All primary subjects and other household members taking part in the study installed a tracking app on their smartphone (*Moves*). The app uses the phone's GPS to passively and continuously record all trips, and distinguishes between ones made by active modes (walk and bike) and by "transport" modes (personal car, transit, Uber/Lyft, friend's car, etc.) without any input from the subject.

A vehicle tracking device (*Automatic*) was installed in the on-board diagnostic (OBD) port of the primary (i.e., chauffeur) vehicle. The device cost $150, raising the total per household cost to $1400. The vehicle tracker collects data on the origin and destination, timing, and route of each trip. It consistently and continuously records and stores the data, ensuring no loss in data throughout the 3-week period.

Participating subjects were also asked to complete a log sheet to note any trips made by any form of public transit or by a non-personal vehicle (Uber/Lyft, friend's car, etc.) to compensate for the limitations of the smartphone tracking app. Similarly, chauffeurs were asked to fill out a log sheet to track the number of people in the car and who was being chauffeured (the owner, a friend, a family member, zero-occupancy trip, etc.).

Finally, data from all these sources were joined to form a single data set that includes all trips made by the primary subject (including trips made by modes other than the personal vehicle) and all trips made by the primary vehicle (regardless of who is in the car).

Methods of tracking and trip logging were systematic and consistent throughout the 3 weeks and for all 13 subjects.

Data collection: surveys

All primary subjects as well as other adult household members formally taking part in the study first took an online entrance survey that collected information on demographics, typical travel patterns, well-being, and knowledge of self-driving cars and attitudes toward the technology. They also completed an exit survey, which was similar to the entrance survey and included an extra section that asked subjects about their experience with the simulated self-driving car experience.

Results

We report results from the 13 primary subjects (1 per participating household), excluding any other participating family members from this analysis as their participation was not consistent across the households. While admittedly a small sample, we present what we believe are the first results from an experiment aimed at capturing the impact of self-driving vehicles on activity and travel in a naturalistic setting. Further, this serves as a beta test for a larger experiment (currently in preparation), and the small sample has the advantage of being able to supplement the quantitative data with personal interactions with each subject. Our first subjects started the experiment on May 29, 2017, completing the experiment 3 weeks later. By August 7, 2017, all subjects had finished the experiment.

Subject socio-demographics

The beta test sample turned out to be diverse in some aspects but homogeneous in others. The participants collectively represented both genders (5 males and 8 females), different ages (from 19 to 78) and cohorts (millennials, families, retirees), several income levels (from < $25 K to $200 K+), and different household sizes (from 1 to 5) and relationship statuses. However, the level of education was homogeneous with almost all subjects having at least some level of college education, and most with a college degree. This is not too surprising given that our recruitment effort reached a relatively wealthy retirement community, a relatively wealthy neighborhood in the San Francisco bay area, and UC Berkeley affiliates. The average age of the millennials was 22, the average age of the families was 38, and the average age of the retirees was 73. Two families had minors in their household, one family had a college-student child with her own vehicle, and the other family was a couple sharing one household vehicle. Four of the retirees were single females, and one was a couple. As for the millennials, three of them were single, and one often carpooled with her boyfriend.

Impacts on travel behavior

Here we present the key findings regarding how the self-driving car simulation experiment impacted travel and activity behavior in our sample. The results are plotted in Figs. 2 and 3. Figure 2 presents more detailed VMT results for all 13 primary subjects (in no particular order) to provide a sense for each individual in the sample. In this figure, we focus on the VMT of the primary vehicle (whether or not the primary subject was in the car) in combination with the VMT of the primary subject (whether or not via the primary vehicle). The VMT is broken down into three components: (1) VMT by the primary subject, whether in the primary vehicle or not (although nearly all travel by the primary subject was in the primary vehicle throughout the full 3 weeks); (2) VMT of the primary vehicle when it was driven without the primary subject but with some other non-chauffeur person (e.g., a friend or a family member), and (3) VMT when the chauffeur vehicle was traveling with only

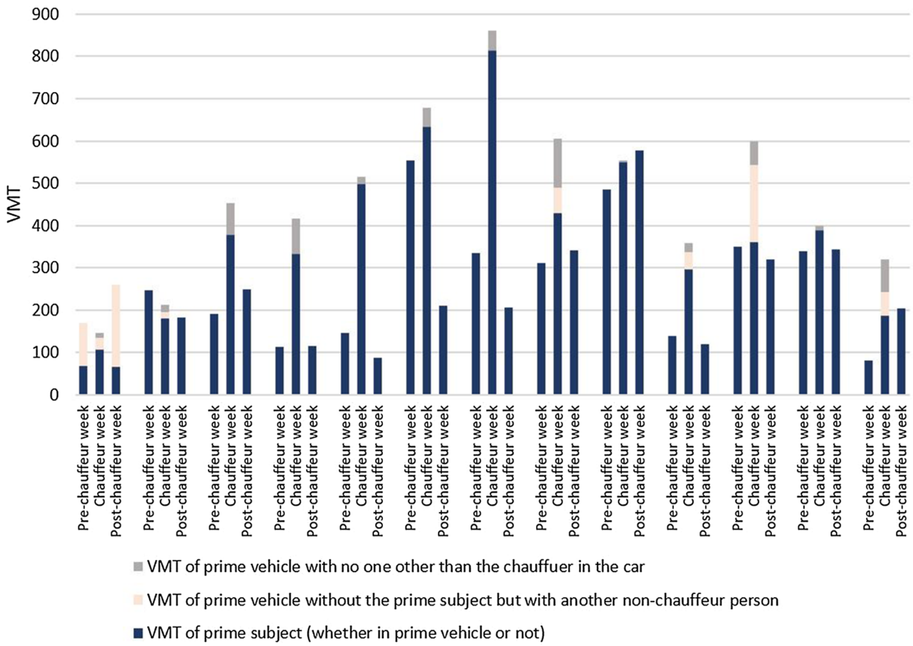

Fig. 2 VMT reported for all primary subjects over each of the 3 weeks

the chauffeur (i.e., a zero-occupancy trip in a self-driving world). Figure 3 summarizes the impacts on a number of key travel dimensions for each cohort and for the sample as a whole. As can be seen in both figures, the two control weeks are fairly similar to each other and distinctly different than the chauffeur week. Accordingly, we focus the analysis on comparing the chauffeur week to the *average* of the pre-chauffeur and post-chauffeur weeks. The key findings are described below.

Finding 1 VMT increased for 85% of the subjects (by amounts ranging from 4% to 341%), and the total VMT from the sample increased by 83% overall.

As shown in Fig. 2, while total VMT decreased slightly during the chauffeur week for the first subject, and hardly changed (on average) for the second subject, the remaining 11 subjects increased their auto travel. The increases in total VMT during the chauffeur week ranged from a low of 4% for one of the Millennials (from 532 to 554 miles) to a high of 341% for one of the Retirees (from 117 to 516 miles), with an overall increase of 83% for the entire sample (from 3344 to 6118 miles).

Our entry and exit surveys provide further insight into these VMT shifts. We asked a wide array of questions to assess views and attitudes toward self-driving vehicles. The responses from the entry survey suggested that subjects would most likely travel more during the chauffeur week. Factors leading to more travel that were ranked most influential by the subjects were: (1) productivity, i.e., people will be able to multitask and make use of their travel time as well as enjoy their commute, (2) zero-occupancy vehicles, i.e., people will be able to send cars out on errands like picking up the groceries, parking, or refueling without having to be present in the car, and (3) convenience, i.e.,

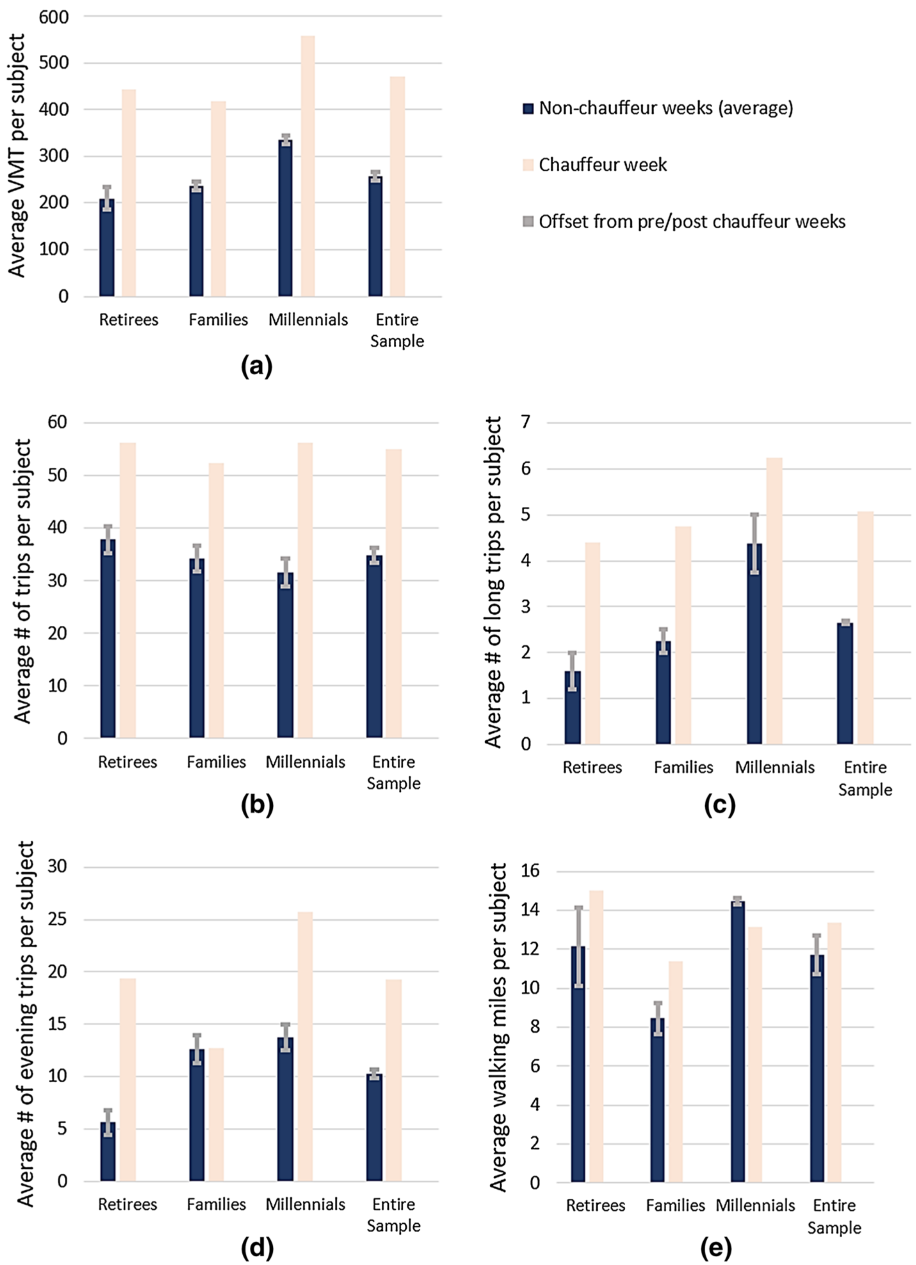

Fig. 3 Shifts in weekly travel and activity patterns for the three cohorts

people will not have to drive and accordingly they are willing to travel on longer leisure trips, or even if under the influence of alcohol and at night when they would be too tired or sleepy to drive themselves.

Our entry and exit interviews also provide further insight. For example, during the recruitment interview, one of the Retirees said that she thought she would not make a good study subject because she spends most of her time inside the neighborhood making short trips. However, when provided with the chauffeur, she increased her auto travel more than three folds. In the exit interview, this subject initially indicated that it was the "novelty" factor that led to such an increase—"I had a chauffeur so I wanted to use it!" However, she followed by saying that with the chauffeur she was able to take longer trips that she had been wanting to take for some time but had not done so when she had to drive herself. So, while there was a novelty factor, there was also the release of latent demand related to lowering the burden of driving.

Finding 2 All subjects sent the car off without them either for errands and/or to escort family/friends, which made up 34% of the total induced VMT; 61% of which was "zero-occupancy" miles (i.e., errands).

At some point during the chauffeur week, all 13 of our subjects sent their "self-driving car" out on errands, with some subjects doing it more frequently than others. There was a wide range of trip purposes, including looking for parking after being dropped off at a destination, sending the car home to wait to be called for pickup, picking up the laundry or a meal, and picking up friends and family while the primary subject was at work or at home. For one Millennial (a single female) and one Family (a family with two minor children), a substantial portion of the induced VMT was from trips taken while the primary subject was not in the car. For the Millennial, running errands (zero-occupancy vehicle) and loaning the car to friends make up 48% and 21% of the induced demand, respectively. For the Family, running errands and driving the kids around without a parent make up 22% and 69% of the increase in VMT, respectively. Looking at the entire sample, sending the car off without the primary subject (the two lighter colors in Fig. 2) accounted for 34% of the total increase in VMT (i.e., 943 of the 2277 miles induced), 61% of which occurred with only the chauffeur in the vehicle (i.e., 582 of the 943 miles). Confirmation via the exit interviews indicated that most (if not all) of this extra VMT was not simply shifted from another vehicle (either within or outside the household) but indeed induced VMT.

Finding 3 Activity patterns changed, with people taking more vehicle trips (on average 58% more), traveling more in the evenings (on average 88% more trips after 6 pm), and taking longer trips (on average 91% more trips longer than 20 miles).

The increase in VMT partially results from Finding 2 above, but also results from a shift in activity patterns as summarized in Fig. 3. Overall, 58% more vehicle trips were taken in the chauffeur week (Fig. 3b). Further, there was a 91% increase in trips longer than 20 miles (Fig. 3c) and 88% more trips taken in the evening after 6 PM (Fig. 3d).

The entrance survey provides more insight into these changes. Related to driving at night, 11 subjects indicated that once they own a self-driving car, they are more likely to participate in more leisure activities after dark because they would not need to drive themselves, and 12 subjects indicated that they would travel more even when they are tired. Moreover, 3 subjects, one from each cohort, indicated that they have a physical condition or anxiety which prevents them from traveling or limits how long they can travel at night. Related to the distance of trips, 11 subjects agreed that they would be more comfortable if they did not have to do the driving, and 12 subjects agreed that they would travel to more distant leisure activities once they own a self-driving car. While increasing the ease of auto travel is hypothesized to impact people's residential choice in the future, only two of our subjects indicated in their exit survey that they believe self-driving cars will result in the relocation of their residence.

Finding 4 The Impact on walking was not clearly directional, with 30% of subjects decreasing their walking (on average by 31% of miles walked) and 70% of subjects increasing their walking (on average by 37% of miles walked).

Figure 3e presents the change in miles traveled by walking during the non-chauffeur versus chauffeur weeks as calculated via the smartphone tracking app. (The results are for 10 subjects since the smartphone app did not work for three of the subjects). It is interesting that this is the only result we have thus far uncovered that is not clearly directional. In this case, 7 subjects increased their walking distance during the chauffeur week, ranging from a 10% to an 80% increase; while 3 subjects, one from each cohort, decreased their walking, ranging from a 28% to a 32% decrease. Further, this statistic showed the greatest variability between the two non-chauffeur weeks. The decrease in walking is hypothesized to be due to replacing walking trips with driving trips and also the pick-up/drop-off feature of not having to walk to access the car. On the other hand, the increase in walking is hypothesized to be due to the more active lifestyle that the self-driving car enabled as represented by the increase in vehicle trips. In our entry survey, when subjects were asked if they are concerned that self-driving cars will decrease the exercise they get from active transportation, only two agreed with this statement, while the rest either disagreed or strongly disagreed.

Finding 5 There were substantial differences across the cohorts.

While a small sample, it is still interesting to note the differences we observe across the three cohorts included in the study. The travel behaviors in the non-chauffeur weeks seem to follow expectations. The retirees drove the fewest miles, although they made a higher number of trips (and therefore shorter trips on average). The retirees traveled substantially less in the evening than the other two cohorts. The millennials traveled the most miles, including (by far) the most long trips. The millennials were also most active in terms of walking, followed by the retirees. The families fell in the middle on all measures except for walking, where they were the lowest.

As with the status quo behaviors, the relative impacts of the self-driving vehicles on the different cohorts are also not surprising. While the retirees traveled the least in terms of VMT, long trips, and evening trips in the non-chauffeur weeks, they increased the most on all three of these measures in percentage terms. Safety, as the retirees highlighted in their exit interview, is of major concern to this demographic as they no longer trust their driving skills as they did before, especially at night. For families, in particular the ones with minor children, the factor that influenced the change in travel behavior the most was the freedom the self-driving car gave the children, which made up a substantial share of the increased travel (Fig. 2). All cohorts, however, enjoyed the convenience of having someone else run errands for them while they conducted other activities. The Millennials, on average, had the largest increase in number of trips and were the only cohort, on average, to reduce walking.

Non-finding We cannot say much about mode choice, because our subjects made zero use of bicycles and hardly any use of public transit or transportation network companies (TNCs) during the three-week experiment and zero use of these modes during the chauffeur week.

Significant discussion about self-driving cars is related to the potential impact of the technology on mode choice, potentially decreasing use of public transportation and of active modes (biking, walking) (Malokin et al. 2015). We had hoped to provide such insight from our study. Unfortunately, the subjects we recruited were heavily auto-oriented, and thus we were not able to examine such impacts because the use of non-private auto modes (other than walking) was almost non-existent in our sample. We were also hoping to get information on substitution with TNC use (Uber/Lyft) as our subjects did report periodically using such services, but we did not observe such use during our study period. This is not too surprising given the fact that owning a vehicle is a prerequisite to participate. Our entry survey confirmed the auto-orientation. When asked about the mode of transport used to get to work/school, all subjects with such a trip indicated they use some form of personal vehicle, either as a driver or a passenger. Moreover, in the entry survey, subjects were presented with scenarios (going to school/work, dinner with friends, grocery shopping, etc.) where they had to choose between public transit and a self-driving car, and they uniformly chose self-driving cars over public transit. Nevertheless, it is noteworthy that while there were a few transit trips recorded outside of the chauffeur week, there was zero use of public transit recorded during the chauffeur week.

Reflections on the experiment itself

A critical question is how successful this experiment was in how well it was able to mimic what life may be like with a self-driving car. To get at this, in the offboarding process we asked a number of specific questions in the survey, asked an open-ended question in the survey, and spoke directly with a number of the subjects.

When asked how much subjects agreed with the statement “the experiment closely replicated life with a self-driving car,” four subjects agreed and one strongly agreed, while another four disagreed and two strongly disagreed, and one subject felt neutral. The use of the word “closely” may have been too strong as in our interviews with the subjects after the experiment, almost all subjects said that the experiment helped them get an idea of how life with a self-driving vehicle may change (or not change) their lives. Perhaps “reasonably” would have been a better word choice.

One of the main issues people had was regarding the chauffeur. The presence of a human in the car detracted from the feeling that it was a self-driving car. For example, some subjects felt guilty about sending the chauffeur on errands like taking care of their dirty laundry or having the chauffeur sit in the car doing nothing for long periods of time waiting for the next trip. Another chauffeur-related issue was that some subjects had multiple chauffeurs assigned during their chauffeur week, and there was an adjustment to each chauffeur. While the vast majority of our chauffeurs lived up to the “professional” claim of the driving service, there were issues with chauffeurs including reported aggressive driving, not showing up on time, and in one case causing a fender bender.

Another issue was the 60-h time budget. A self-driving car will be available 24/7 and not only 60 h a week. We asked the subjects to submit a plan to allocate their 60 h a week in advance so that we could schedule the chauffeurs. While they were able to make relatively dynamic adjustments to the schedule (e.g., a few hours in advance), some reported that pre-planning their week took away the spontaneity that self-driving cars offer.

Finally, there was a novelty issue. Subjects felt that 1 week was not enough to really get into a routine and a lifestyle in which they owned a self-driving car. For some subjects, although they already knew they could send the chauffeur on errands, it took them a couple of days to internalize the idea and actually do so.

With all these limitations, however, subjects still felt that they learned something from the experiment, and that they got a better sense of how their life might be once self-driving cars become available. In the exit survey, one Millennial summarized his experience as: "with all the limitations of the experiment, I definitely felt the benefits of a self-driving car. I noticed that I reach work less tired, I noticed that I can do work on my way back home and not worry much about traffic jams, and I noticed that my commute overall feels more pleasant."

Another Millennial highlighted the multitasking potential: "A self-driving car would be super helpful for multitasking! I would use self-driving cars a lot more for thoughtless activities that don't need me present. One thing that I noticed was that I was willing to use my car a lot more frequently to accommodate my friends and family. It also made going out and drinking a lot easier."

In their exit survey, a Family mentioned what, to them, was the most important benefit of having the self-driving car: "I spend a lot of time in the car driving my kids around to activities. Having a self-driving car would enable me to spend more time on work and would afford my kids more freedom."

Finally, a Retiree reported: "At my age, I am looking forward to the independence a self-driving car will provide as my driving skills decline. I believe self-driving cars will improve safety in driving, a real boon."

Conclusion

Researchers seem to agree that self-driving cars will increase individual vehicle-miles traveled and change travel and activity patterns. However, the predicted magnitude of the VMT increase varies considerably and the ways in which people may change activities (number, location, duration, type, timing, etc.) are largely uncertain. Our objective was to provide insight into these questions by employing a naturalistic experiment to project people into a futuristic environment via the use of chauffeurs. From the experiment, we are able to provide a new kind of data to shed light on these issues. While our sample is small, it represents real data from real people making adjustments in their everyday lives. We found an 83% overall increase in VMT. The number of long trips (> 20 miles) and trips after 6 pm increased by 91% and 88% respectively. Retirees were the cohort with the largest increase in these two trip types (175% and 246% respectively). 21% of the increase in VMT was a result of "zero-occupancy" vehicles, where subjects sent their chauffeur on errands. For active transport, namely walking, there was a bidirectional impact in that 30% of the sample reduced their walking and 70% increased their walking. Comparing the unique impact the chauffeur service had on the travel behavior of the different cohorts, we observe unsurprising differences. The retirees, for example, benefited from the ability to travel at night and on longer trips without having to worry about safety. For families, children were chauffeured to activities without their parents, giving the children more freedom to travel and the parents more time to focus on other activities. These results provide new insight to the growing body of knowledge regarding our future with self-driving vehicles. Future work includes refining the experiment based on this beta test, increasing the size and diversity of the sample, and estimating travel demand models in order to quantify changes in utility under self-driving car scenarios.

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